

Moon's 'Abundant Resources' Largely an Unknown Quantity

Will we find enough raw materials, in accessible enough places, to power Bush's proposed lunar base?

It's 2014. Forty-five years after the Apollo 11 landing, humans return to the moon to set up the lunar base that President George W. Bush proposed a decade earlier. Which will they be: homesteaders or campers?

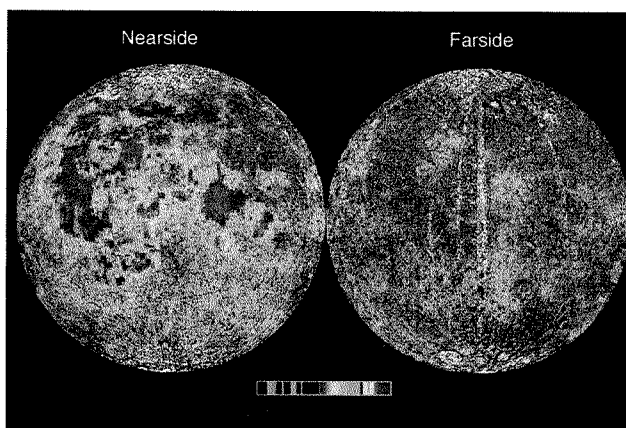
Apollo astronauts, who roved the lunar surface for tens of hours, could easily bring with them enough food, water, and air for a short visit. Under NASA's ambitious new plans for lunar exploration, however, astronauts will live on the moon for weeks or months at a time—and the longer they stay, the more difficult and expensive it becomes to supply them from Earth. Some space boosters, the president included, suggest that part of the solution lies in living off the land. "The moon is home to abundant resources," Bush stated in his 14 January speech announcing NASA's new vision. Scientists agree that potentially useful chemicals, such as water ice and various gases, are indeed locked up in lunar soil. But when it comes to estimating how abundant they are and how practical it would be to extract them, one resource still in short supply is information.

Water. More valuable than gold to a lunar base, water can be used for drinking or it can be split to create oxygen to breathe—or oxygen and hydrogen for rocket fuel. A few tons of hydrogen-oxygen fuel could send a rocket off the surface of the moon and into space. That's why moon buffs such as Paul Spudis, a planetary scientist at Johns Hopkins University's Applied Physics Laboratory in Laurel, Maryland, think the most important lunar resource is likely to be water from ice.

In theory, ice from crashed comets may linger in cold, dark niches at the lunar poles, from which it could relatively easily be extracted and distilled. But scientists disagree about how much of it is trapped there. In 1996, a Department of Defense satellite called Clementine bounced radar waves off the moon's surface and back to radar telescopes on Earth. Spudis and colleagues noticed that reflections from shadowy nooks near the lunar south pole could be interpreted as signatures of multiple scattering within crystals of water—an indication that about 1.5% of the lunar soil in those regions is water ice.

Similar results came when the Lunar Prospector satellite, launched in 1998, used a spectrometer to count neutrons bouncing off the moon in energy ranges known to interact with hydrogen—presumably in water ice. The answer: Patches of polar lunar soil were about 0.5% to 1% ice by weight—less water than Clementine found, but still enough to make a polar base attractive.

On the other hand, Donald Campbell, a physicist at Cornell University, and colleagues twice bounced radio waves off the moon from the Arecibo telescope in Puerto Rico but saw no signs of water ice. "We don't believe that the radar data supports" the large amounts of ice that the Clementine analysis would imply, Campbell says. And when the Lunar Prospector crashed into the moon's



Orb of plenty? Titanium minerals mapped by the Clementine orbiter (red areas) may contain useful amounts of oxygen and helium.

south pole at the end of its mission, scientists didn't see water in the resulting plume of debris. Spudis thinks a more energetic crash would have splashed up water vapor, but for now, lunar water remains an open question.

Trapped gases. Even if there's little water on the moon, astronauts might be able to make it and other useful chemicals from more-abundant raw materials: light elements such as nitrogen, oxygen, and carbon, manufactured by nuclear fusion inside the sun and blown to the lunar surface on the solar wind. These trace elements are present in the lunar soil, or regolith, at levels of parts per million, so it would take a huge amount of mining to get usable quantities. The good news is that they are extremely easy to extract: Just heat

soil up (using the base's solar or nuclear power source) and the gases escape, yielding nitrogen, carbon monoxide, carbon dioxide, methane, and hydrogen that can be converted into air or water. Water, in turn, can be used to strip oxygen from a common iron-titanium lunar mineral known as ilmenite.

Helium. Even more valuable in the long run may be a much rarer legacy of the solar wind, helium-3. Only Earth-bound humans would benefit, however, and even its enthusiasts acknowledge that it's a long shot.

Helium-3 is attractive because it can fuel an advanced fusion reactor. A helium-3 atom combined with a hydrogen-2 (deuterium) atom or with another helium-3 releases a great deal of energy with relatively little radioactive waste. "If we replaced all the electrical power plants in the United States with [helium-3/deuterium] reactors, you'd need only 40 metric tons to produce all the electricity needed in 2004," says Gerald Kulcinski, a physicist at the University of Wisconsin, Madison. Only a few hundred kilograms of helium-3 are accessible on Earth, he says, but the lunar regolith harbors millions of tons of it.

Several factors make mining helium-3 a dicey proposition. For one, most of the solar wind strikes the lunar far-side, which faces the sun when the moon's orbit takes it upwind of Earth's magnetic shadow. But ilmenite, the only lunar mineral that traps helium-3 effectively, is more common on the moon's near-side. Wherever it crops up, even helium-3-rich lunar soil won't contain much of the gas. "It'll be a little better than 10 parts per billion by weight," says Timothy Swindle, a geochemist at the University of Arizona in Tucson. "To make a dent in the world's energy needs, you're going to have to mine a large fraction of the surface of the moon." Physicists will also have to

create a working helium-3 reactor—no easy task, considering that decades of research have yet to produce a fusion power plant of any sort. And, of course, someone will have to ship all the helium back to Earth.

The bottom line: Before investing in helium futures or moon air and water rights, wait for scientists to figure out how much of these resources there are and where they reside. NASA's 2005 budget contains money to begin exploring the moon with robot missions—including, presumably, prospectors. Their work will reveal whether visiting astronauts will be able to eke out an existence from the lunar soil, or whether the rest of us will have to foot a literally astronomical delivery bill.

—CHARLES SEIFE